Performance Evaluation of 1479nm-1555nm Band Erbium Doped Fiber Amplifier for 96 Channels DWDM System

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Abstract

This research is an attempt to reduce the gain variation, noise figure and to improve the gain broadness of EDFA by modified mathematical modeling of EDFA for 96 DWDM systems. An improved simulated model of EDFA is specially designed after all the major impairments are taken into account like noise, ASE fiber length, input pump and signal power. The mathematical model of EDFA has been proposed by improving the rate equations of EDFA. Variation of gain versus wavelength has been analyzed with and without ASE. This research claims to support 96 DWDM channels at a channel spacing of 0.8 nm, with a gain of 23.8 dB, ASE of 0.9 dBm for 6 m EDF length for 1479 nm-1555 nm EDFA.

Keywords

ASE; DWDM; EDFA;GAIN; NF

Introduction

The main parameters in the design of an EDFA include the fiber glass material, the waveguide characteristics of the fiber, the erbium concentration profile, fiber length, pump sources and any active or passive components such as couplers, isolators, filters etc. The design of the amplifier depends on the intended application, however, the primary design goals are high gainand output power, low noise figure, the flat gain spectrum, reliability, etc. The importance of each of these parameters depends on the particular application type. For example, a single-channel inline amplifier requires high power and low noise figure, but the gain flatness is insignificant. On the other side, in the design of a DWDM amplifier, broad gain profile is the most critical parameter. Power amplifiers require high gain and output power and may not have constraint on the noise figure and gain flatness. Analog amplifiers are the most demanding since all the described parameters are important to amplify the signal keeping the waveform as much undistorted as possible. So, one of the main issues when EDFA amplifies multi-wavelength signals is the gain broadness in the used wavelength range. Previous works showed that maximum gain flatness is achieved when average inversion population is in the range from 0.75 to 0.8, which implies that when EDFA operates in the saturation regime, it is not suitable to work in DWDM system. Various gain broadening techniques of EDFA are available. The aim of this work is to optimize EDFA parameters in order to obtain high gain broadness and low noise figure.

Modeling of EDFA for Dynamic Effects

The basic operation of EDFA is shown in Fig. 1.

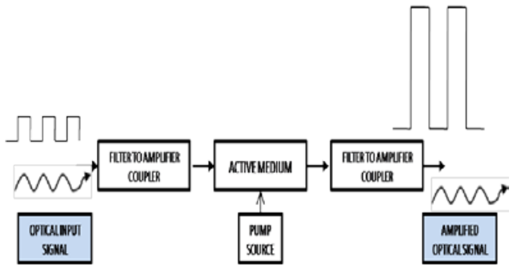

FIG 1 THE BASIC OPERATION OF EDFA

The three level energy diagram of EDFA is considered in which the signal gain is achieved by a metastable population of excited ions by emission decay from a higher pumped state. In this section, modeling of EDFA is proposed using improved rate equations of a three state EDFA by considering forward ASE. Figure (2) describes three level energy diagram of EDFA with various energy transitions. The three population states of Er^{+3} are ground state (g) with population density of n_g, the metastable state (m)with population density of n_m which is related to signal frequency and excited state (e) population density of n_e which is related to

pump frequency. The total population of erbium ions at these three states is assosiated with the population density (ϱ) of erbium ions.

$$n_e + n_m + n_g = \rho \quad (1)$$

The important transition in this case is from ground state to metastable state, the energy difference among these states corresponds to about 1550 nm. Let Pge be the pumping rate from ground state (level g) to excited state (level e), Peg and Pem be the stimulated emission rate from excited state to ground state and metastable state, respectively. It is assumed that Peg is not considered as an important transition. There are two types of transitions occuring in excited state, one of which is radiative transition and the other is non-radiative transition. The radiative transition from excited state is further of two types i.e. upto metastable state (level m) and upto ground state i.e. Aem(r) and i.e. Aeg(r) respectively. It is also considered that the transition is mainly non-radiative, which implies that non-radiative transition (Aem(nr)) radiative transition(Aem(r)Aeg(r)). Let the rate of stimulated absorption and emission be Sgm and Smg respectively. The rates of spontaneous emission from metastable state are also radiative and non-radiative in nature, at this level radiative transition (Amg(r)) non-radiative transition (Amg(nr)). The non-radiative transition from excited state and radiative transition from metastable state are considered as ne/τ′ and nm/τ, separately, where τ′ and τ are the respective transition rates. The energy transistion of EDFA is shown in Fig. 2.

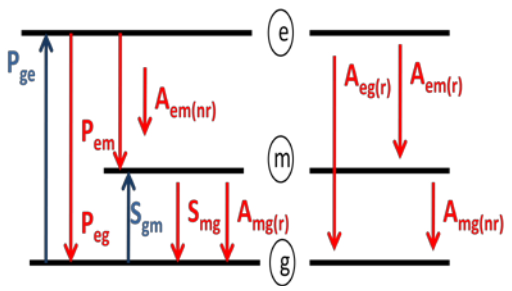

FIG 2 ENERGY TRANSITIONS IN A THREE LEVEL EDFA

Therefore, the improved rate equations of the three states for this proposed model are shown in Eq. 2-4:

$$\frac{\delta n_g}{\delta t} = \begin{pmatrix} -P_{ge}\, n_g \;- S_{gm}\, n_g \\ +S_{mg}\, n_m + \frac{n_m}{\tau} + P_{eg} n_e + \frac{n_e}{\tau'} \end{pmatrix} \quad (2)$$

$$\frac{\delta n_m}{\delta t} = \left(S_{gm}\; n_g \;- S_{mg}\; n_m - \frac{n_m}{\tau} + P_{em}\, n_e \right) \quad (3)$$

$$\frac{\delta n_e}{\delta t} = \left(P_{ge}\; n_g \;- P_{em}\; n_e - \frac{n_m}{\tau} - P_{eg} n_e - \frac{n_e}{\tau'} \right) \quad (4)$$

Considering the assumptions on the probability of occurrence of transition from excited state to metastable state (which is more as compared either to that from excited to ground state or from metastable state to ground state) and total population inversion, the equation (4) becomes

$$\frac{\delta n_m}{\delta t} = \left(S_{gm}\; n_g \;- S_{mg}\; n_m - \frac{n_m}{\tau} + P_{ge}\, n_g \right) \quad (5)$$

The equation (5) can be represented by means of block diagram shown in fig.3.

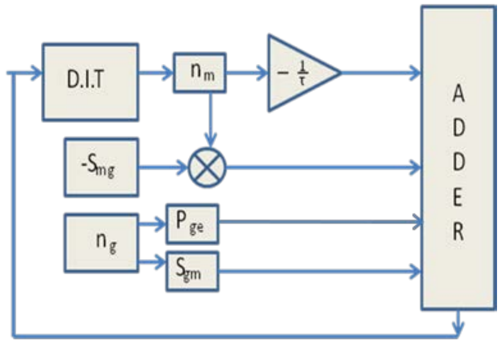

FIG 3 BLOCK DIAGRAM REPRESENTING POPULATION DENSITY OF ER+3 IONS IN METASTABLE STATE

The signal and pump rates(Sgm, Smg) which are dependent on cross-sectional are of core (A), absorption and emission cross section data (σ) of erbium fiber and confinement factors for pump and signal waves (Γ) can be defined as:

$$S_{gm} = \frac{\Gamma_s \sigma_{gm} P_s}{A} \quad (6)$$

$$S_{mg} = \frac{\Gamma_s \sigma_{mg} P_s}{A} \quad (7)$$

The pumping rate from ground state to the excited state can be represented in terms of pump power, confinement factor for pump by equation (8)

$$P_{ge} = \frac{\Gamma_p \sigma_{ge} P_p}{A} \quad (8)$$

On considering scattering losses of the erbium doped fiber negligible, the rate equation for the population (5) can be rewrite as:

$$\frac{\partial N_m}{\partial t} = P_s(0,t) - P_s(L,t) + P_P(0,t) - P_P(L,t) - \frac{N_m}{\tau} \quad (9)$$

Equation (9) represents the population density Nm as a function of position along the fiber without considering the ASE. The last term in R.H.S. of equation (9) is the decay in metastable state originating from spontaneous emission, and the rest of the terms combines both absorption and emission due to fields. Regarding the effect of co-propagating ASE, the equation (9) becomes:

$$\frac{\partial N_m}{\partial t} = P_s(0,t) - P_s(L,t) + P_P(0,t)$$
$$-P_P(L,t) - \frac{N_m}{\tau} + P_{ASE}^{+}(0,t) - P_{ASE}^{+}(L,t) \quad (10)$$

Where, ASE power, pump power and Signal Power are shown in Equation (11)

$$\frac{P_{ASE}^{+}(L,t)}{P_{ASE}^{+}(0,t)} = 2h\nu\Delta\nu\left[(G-1)+\frac{\beta}{\rho A}N_m\right]$$

$$\frac{P_P(L,t)}{P_P(0,t)} = exp[B_p\, N_m - C_P]$$

$$\frac{P_s(L,t)}{P_s(0,t)} = exp[B_S\, N_m - C_S]$$

Where, $B_P = \frac{\Gamma_P\, \sigma_{ge}}{4.3429A}$, $B_S = \Gamma_s\frac{\sigma_{mg}\; + \sigma_{gm}}{4.3429A}$, $C_P = \rho L\Gamma_P\, \sigma_{ge}/4.3429$,

$$C_S = \rho L\Gamma_S\sigma_{gm}/4.3429 \qquad (11)$$

The equation (11) is considered according to Bononi and Rusch's notation. The improved rate equation of metastable state is shown in equation(12):

$$\frac{\partial N_m}{\partial t} = P_s(0,t)[1-exp(B_S\, N_m - C_S)] + P_P(0,t)[1-exp(B_P N_m - C_P)] - \frac{N_m}{\tau} - P_{ASE}^{+}(0,t)\left[1-2h\nu\Delta\nu(G-1)+2h\nu\frac{\beta}{\rho A}\Delta\nu N_m\right] \qquad (12)$$

The equation (12), the primary equation to describe the dynamic gain effects in the three level EDFA including ASE, can be modeled using SIMULINK as already proposed in. In this work, the improved non-linear ordinary differential equation is implemented as a MATLAB Simulink model(shown in figure (4)), including the impact of ASE. Algorithm and Flowchart used for simulation of proposed SIMULINK model of EDFA is as follows:

Algorithm I Algorithm_Sim_EDFA

STEP I: Initialize ng, nm and ne (Er+3 ion densities at ground, metastable and excited states), A(area), L(length of Fiber), Pp&Ps (Pump and Signal Power), λp&λs (Pump and Signal Wavelength), ASE power

STEP II: ng, nm, ne and L=variable

STEP III: Calculate ion of Er+3 in metastable state and length of EDF

STEP IV: Calculate Gain, ASE Power and Output Power with respect to Length of Fiber

STEP V: Calculate Optimum Length of fiber for maximum gain and minimum ASE power

STEP VI: Plot gain, NF for optimum length of EDF w.r.t.wavength

STEP VII: Goal Achieved

By means of Algorithm I and figure (4), the graph is plotted between gain and wavelength (without considering ASE) for EDF length ranging from 4 m to 14 m as shown in figure (5)which implies that the length 14 m can be chosen as optimum length, because at this length peak gain of 32 dB is obtained while for 6 m its value is 26.5 dB and for 4 m its value is 20 dB.

The main goal of this work is to define the optimum value of EDF length so that gain broadness is maximum in the largest possible wavelength range.

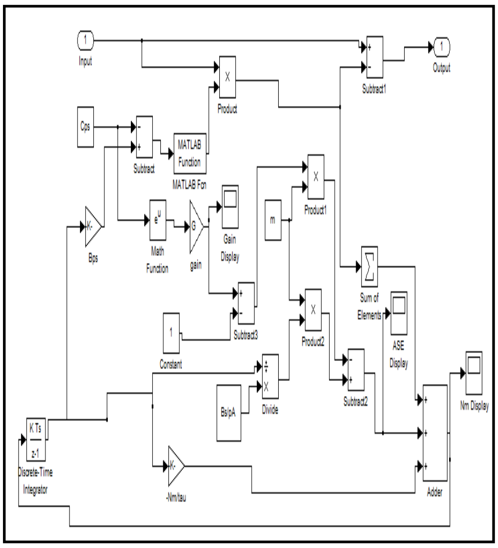

FIG 4 IMPROVED SIMULINK MODEL OF EDFA

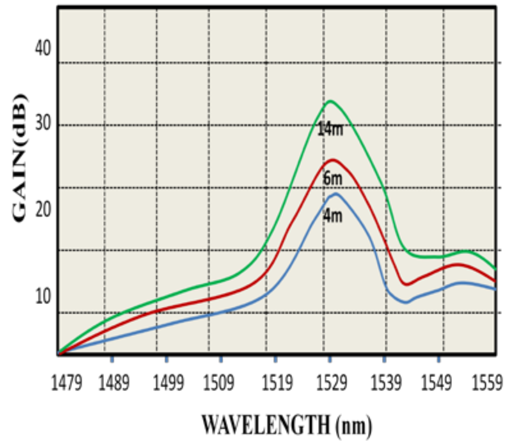

FIG 5 GAIN VERSUS WAVELENGTH FOR DIFFERENT FIBER LENGTHS WITHOUT ASE

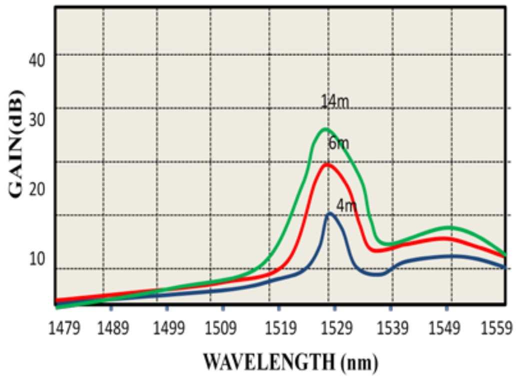

FIG 6 GAIN VERSUS WAVELENGTH FOR DIFFERENT FIBER LENGTHS WITH ASE

To obtain the optimum fiber length, gain of EDFA is plotted as shown in figure (6) by taking the effect of co-propagating ASE into consideration for length of EDF ranging from 4 m to 14 m. When ASE is included,

the optimum length for gain is determined by maximizing the signal gain which is a function of the length. It has been observed that the gain peak is reduced from 32 dB to 26 dB for 14 m length, from 26.5 dB to 23.8 dB for 6 m length and from 21 dB to 15.5 dB for 4 m length. It has been clear from figure 7 that there is a very insignificant difference in gain peaks for 14 m length and 6 m length. So, it is concluded from figure 6&7 and Algorithm I that the fiber length of 6 m is considered as the optimum length for pump power of 17.6 dBm.

The simulation results presented in figure (5) and Figure (6) can be summarized in Table 1.

TABLE 1 SIMULATION RESULTS

Without considering ASE		Considering ASE		
Length (m)	Max. Gain (dB)	Length (m)	Max. Gain (dB)	ASE Power (dBm)
4	21	4	15.5	0.7
6	26.5	6	23.8	0.9
8	27.2	8	24.0	4.6
10	28.3	10	24.5	7.5
12	30.1	12	25.8	9.1
14	32	14	26.5	11.8

The results show that EDF length of 6 m can be considered as optimum length and for this length the gain and noise figure are plotted with respect to operating wavelength as figure(7) which shows improvement in broadness of gain spectrum.

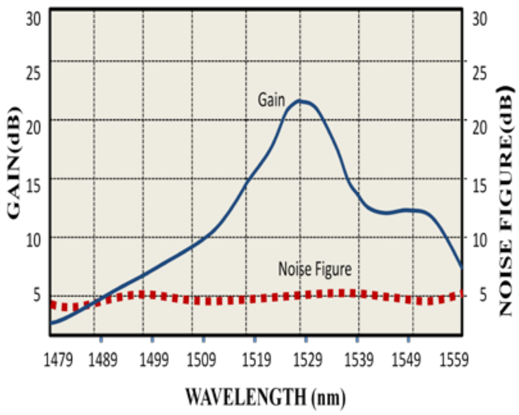

FIG 7 GAIN AND NOISE FIGURE VERSUS WAVELENGTH

Conclusions

The improved SIMULINK model enhances the broadness of gain spectrum of EDFA. The optimized values of population densities, cross-section areas of absorption and emission spectra, length of EDF, pump powers are considered. Though ASE is considered, even then broadness of gain spectrum gets improved, because a compromise for optimal length at which ASE is negligible is made, the value of maximum gain is lowered.

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